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PROBABILISTIC RISK ASSESSMENT FOR THE LOS ALAMOS MESON PHYSICS FACILITY WORST-CASE DESIGN-BASIS ACCIDENT

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ABSTRACT

This paper presents results from a Los Alamos National Laboratory Engineering and Safety Analysis Group assessment of the worse-case design-basis accident associated with the Clinton P. Anderson Meson Physics Facility (LAMPF)/ Weapons Neutron Research (WNR) Facility. The primary goal of the analysis was to quantify the accident sequences that result in personnel radiation exposure in the WNR Experimental Hall following the worst-case design-basis accident, a complete spill of the LAMPF accelerator 1L beam. This study also provides information regarding the roles of hardware systems and operators in these sequences, and insights regarding the areas where improvements can increase facility-operation safety. Results also include confidence ranges to incorporate combined effects of uncertainties in probability estimates and importance measures to determine how variations in individual events affect the frequencies in accident sequences.

I. INTRODUCTION

The Los Alamos Meson Physics Facility (LAMPF)/Weapons Neutron Research (WNR) Facility is one of a complex of research facilities at the Los Alamos National Laboratory (LANL) that uses accelerated ion output from LAMPF. LAMPF Line D/1L ions are transported to the WNR Neutron Scattering Experimental Hall (ER-2) where they produce neutrons for nuclear structures or reactions investigations. Normal WNR operations are associated [illegible] hazards, such as penetrating radiation produced by ion/nucleus impact and delayed radioactive emissions from activated materials. ER-2 personnel are protected from these hazards primarily by shielding and passive personnel barriers. In contrast, errant-beam-delivery accidents require both shielding and quick-response active mitigation system protection because of the potential for rapid accumulation of a large radiation dose. This paper quantifies the risk associated from a LAMPF facility design-basis beam-spill accident initiated by failure of a high-field type-C 1LMP01 90° beam-steering magnet. This single initiator has occurred at a historical rate of 0.01/yr .

II. ACCIDENT SEQUENCE ANALYSIS

A. System responses

A total of 4 Ionizing Radiation (IR), 4 Gamma Detector (GD), and 13 Neutron Detector (ND) chambers should detect the increased ER-2 radiation levels resulting from the accident initiator. As described below, these detectors and their electronic-monitoring equipment interact with three systems— Fast Protect (FP), Run Permit (RP), and the Radiation Security System (RSS)—to eliminate the radiation hazard created by the resulting beam/structure interaction.

The primary purpose of FP, which is comprised of two redundant systems, is to minimize equipment activation by interrupting beam delivery when a beam spill extends beyond established limits. However, either of the two FPs can also provide personnel protection by rapidly interrupting beam on a pulse-to-pulse basis by electrostatic deflection. The FP systems also automatically generate a gate pulse that shuts off LAMPF ion beam sources.

RP is a system of interlocks and logic designed for two purposes: (1) to ensure correct configuration prior to beam delivery and (2) to continuously monitor the status of selected operating parameters during beam delivery. RP also provides protection by generating an ion-source turn-off pulse and by causing a single plug (TBBL02) to insert into the beam path in response to a change in 1LMP01 magnet excitation current.

The RSS is the only safety-grade radiation protection system at LAMPF. The RSS employs fail-safe component logic configurations and redundancy as part of a passive personnel barrier to exclude personnel from access to any direct beam. RSS also incorporates radiation detectors (GD and NDs) that operate to terminate spill accidents by causing two pairs (TBBL01/01BL01 and LDBL01/LDBL02) of plugs to be inserted into the beam path.

Automatic beam deflection, ion-source turn off, or plug insertion all result in elimination of the ER-2 radiation hazard created by an errant beam. However, if all of these automatic systems fail, LAMPF operations personnel can still manually shut off ion sources in response to RP, and RSS audible or visual alarms.

B. Accident-sequence event tree

The accident-sequence event tree for the LAMPF accelerator 1L beam spill initiated by a 1LMP01 90° beam-steering magnet failure is shown in Fig. 1. For this analysis, several systems, such as the two FP electronics and their associated deflectors, were consolidated into single event tops in order to minimize the number of sequences. The following section discusses the general procedures used to quantify event-tree branch probabilities.

III. SYSTEM ANALYSES

Referring to Fig. 1, there are 11 system responses to the 1LMP01 90° beam-steering magnet initiator design-basis accident (DBA). These responding mitigating systems can be grouped into four categories: sensors and analog electronic monitors, relay-logic systems, mechanical beam-plug systems, and operator-recovery actions with ion source shut off. Discussion of the failure analyses for these system categories follow.

A. Sensors and analog electronic monitors

The sensor and analog electronic monitor systems include: the IR(4), GD(4), ND(13), and RP systems as well as the two FP/deflector pairs that are combined into the single "Beam is Deflected" top event. Each of these combines a radiation chamber or current (RP only) sensor with a monitoring circuit that causes at least one relay in the RSS logic string to open when the monitored signal moves outside a preselected range.

Event-tree branch probabilities for the sensor and monitor systems were calculated using the Set Equation Transformation System (SETS) code[1] to solve their fault trees. Individual system fault trees were constructed using LAMPF drawings to identify hardware failures and operations manual test procedures as source documentation for human errors. Human Error Probabilities (HEP) were calculated using historical data, when available, or the Technique for Human Error Rate Prediction (THERP).[2] Additionally, we assumed the ND microprocessor instruction set was 100% reliable.

Sensor and analog electronic monitor system fault trees also include combinations of independent and common-cause failures for the redundant IR, GD, and ND systems. These common-cause failure probabilities were quantified using the Multiple Greek Letter Model.[3]

B. Relay-logic system

SETS was also used to solve for the RSS logic system event-tree branch probability. Detailed discussion of the RSS fault tree is included in a previous LANL Safety Analysis Group study.

The majority of the failure rates used to determine hardware basic event values for the RSS and the sensor and analog electronic monitor systems were calculated using Military Standard HDBK-217E.[4] Error factors (EF) for these events were found by varying hardware environmental stress factors over a reasonable range and computing

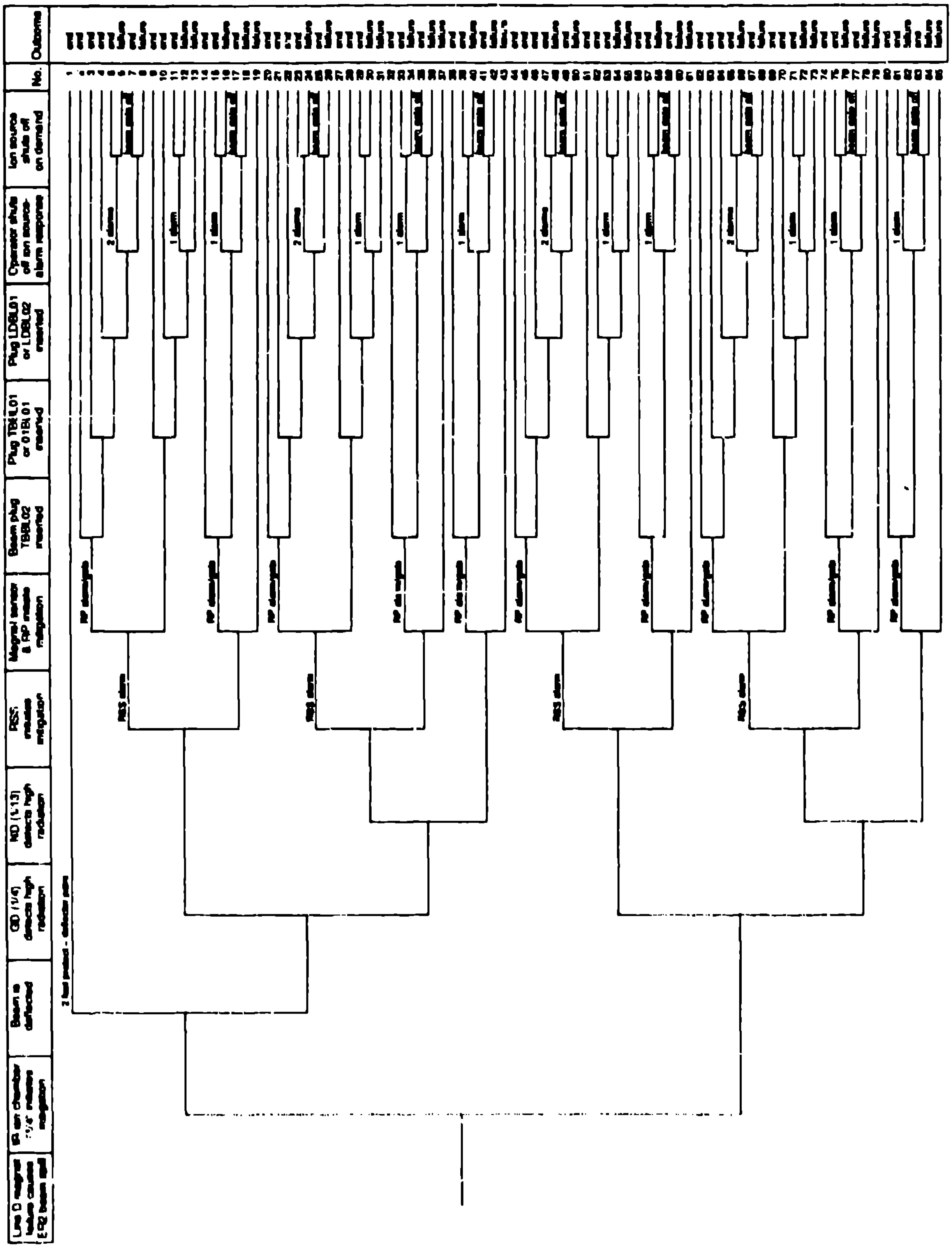

FIGURE 1 EVENT TREE FOR ANALYSIS SCENARIO

the resultant change in failure rates. The source for a smaller number of hardware failure rates and EFs was IEEE Standard 500.[5]

C. Mechanical beam plugs

A total of five beam plugs can be inserted into a LAMPF beam path in response to the initiating event. The successful opening of an RSS logic-string relay in response to a radiation-monitor system trip causes two pairs of plugs to be simultaneously inserted into the beam path. One pair, TBBL01 and 01BL01, is inserted into a low-energy beam region while the other pair, LDBL01 and LDBL02, intersects an accelerated beam. Plug TBBL02, however, is inserted only when the 1LMP01 magnet excitation current moves out of a specified range. The branch probability for TBBLO2 is the LAMPF historical demand-failure rate for single plugs. Branch probabilities for both of the plug-pair top events were calculated by summing two single plug point values with a value for the common-cause failure of both plugs. A generic β (beta) factor of 0.1 was used for this dependent failure of two-similar-component event.

D. Operator-recovery actions with ion source shut off

The four LAMPF control room operators are alerted to the occurrence of an automatic RSS trip by an audible vocal alarm and an alerting control-console alarm. Procedures require an operator to verify beam shut off by interrogating various status indicators and monitors. If the beam is not off, the operator is trained, but not required by procedure, to depress the LAMPF SCRAM switch, and toggle-off all four ion sources.

An RP trip generates only a single alerting control-console alarm, but the resultant operator actions are the same. A standard human reliability analysis (HRA)[2,6] was performed to assign the single-alarm and double-alarm operator-recovery event-tree HEP branch values. No attempt was made to determine the reliability of the computer interrogation or control software; it was assumed to be 100% reliable (this system is currently planned for future study).

The detailed analysis of the circuitry that provides the automatic ion source shut-off gate pulses was not complete by paper submittal deadline. We assumed the gate circuitry is at least as reliable as the most reliable system providing a ion shut-off trip, the RP system, and assigned the RP value to the ion source shut-off top event.

E. System analyses results

Branch failure median values and error factors for the 11 event-tree system responses are listed in Table 1. Analysis quantification, post-processing, and uncertainty results were obtained using the Set Evaluation Program (SEP) code.[7]

With the exception of the FP system, the unreliability of each system was in the range of 10^{-3}. FP is not a system that incorporates safety-grade features, such as redundancy, and therefore its high unreliability reflects a high degree of single-failure susceptibility. Even with its high failure probability, including FP in the analysis as a mitigating system does lower the total accident-sequence frequency.

IV. EVENT-TREE SEQUENCE RESULTS

The Sandia Event Tree (SANET)[8] code was used to both construct the analysis event tree and to quantify its accident sequences using the fault-tree linking method.[9,10] This 11-top event tree has a total of 85 sequences, of which 34 have the potential to result in an undesired radiation-exposure outcome.

The total accident-sequence exposure frequency is 8.2×10^{8}/yr with an error factor of 22. The solution set has five sequences with frequencies greater than 1×10^{10}/yr and five sequences having frequencies between 1×10^{10}/yr and 1×10^{12}/yr. The remaining 24 exposure sequences have frequencies lower than 1×10^{12}/yr.

As seen in Fig. 2, which illustrates the percentages of total exposure-frequency resulting from three classes of accidents, the dominant accident sequences involve simultaneous failures of the FP, the RSS, and the RP systems. The high unreliability of the FP is the largest contributor to these dominant sequences, whereas RSS and RP reliabilities are reasonable for safety-grade systems. A reduction in the point value of the FP system to a value comparable to the other radiation-protection systems lowers the total accident sequence frequency by approximately 95%.

TABLE 1 EVENT-TREE SYSTEM VALUES

Event Top		Median Value	EF
IR ion chamber (1/4) initiates mitigation		2.3×10^{-3}	4.8
Beam is deflected		0.4	4.1
GD(1/4) detects high radiation		1.0×10^{-2}	5.5
ND(1/13) detects high radiation		1.5×10^{-3}	1.8
RSS initiates mitigation		1.0×10^{-2}	5.5
Magnet sensor & RP initiate mitigation		5.0×10^{-3}	3.3
Beam plug TBBL02 inserted		4.20×10^{-3}	5.0
Plug TBBL01 or 01BL01 inserted		4.20×10^{-3}	5.0
Plug LDBL01 or LDBL02 inserted		4.20×10^{-3}	5.0
Operator shuts off ion source:	1 alarm response	7.1×10^{-3}	10.0
	2 alarm response	7.6×10^{-3}	10.0
Ion source shuts off on demand		5.0×10^{-3}	3.3

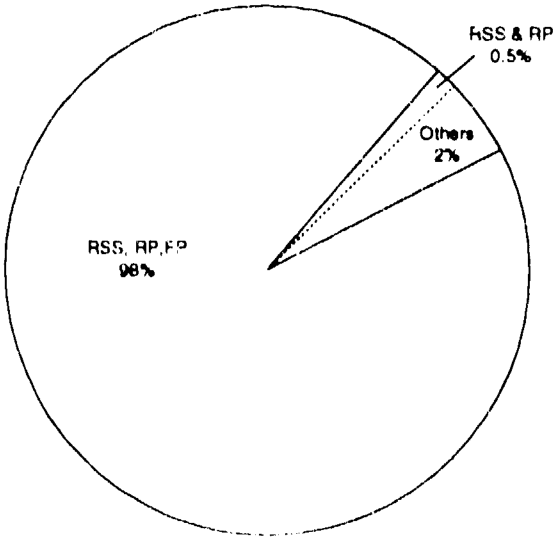

FIGURE 2 ACCIDENT EXPOSURE FREQUENCY CONTRIBUTION RESULTING FROM THE LOSS OF FUNCTION ON RSS, RP, AND FP SYSTEMS

V. CONCLUSIONS AND RECOMMENDATIONS

The analysis outlined in this paper was significant for four reasons. First, we developed a comprehensive documentation and analytical information database for each radiation protection system at LAMPF WNR. Second, we determined that the risk associated with the worst-case DBA scenario at the LAMPF WNR Facility is within range of the guideline (10^{-6}/yr) suggested by a LANL accelerator safety workshop[11] review panel. We also showed that improvements in the FP system significantly lower the risk from this DBA. Lastly, we demonstrated the utility of a PRA for accelerator facilities.

VI. FUTURE WORK

Our immediate plans are to complete the analysis of the circuitry that generates the automatic ion source shut-off gate pulses and to include a software reliability analysis as part of the ND and operator-recovery action systems. Upon completion of these tasks, we intend to perform the consequence analysis associated with the DBA discussed in this paper, evaluate other LAMPF accident scenarios, and develop a general database on the reliability of accelerator safety systems.

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